Children's metabolic expenditure during object projection skill performance: New insight for activity intensity relativity

Ryan S. Sacko[1], Danielle Nesbitt[2], Kerry McIver[3], Ali Brian[2], Farid Bardid[4,5], David F. Stodden[8]

[1] *Department of Health and Performance, The Citadel, USA*

[2] *Department of Physical Education, University of South Carolina, USA*

[3] *Department of Exercise Science, University of South Carolina, USA*

[4] *School of Education, University of Strathclyde, UK*

[5] *Department of Movement and Sports Sciences, Ghent University, Belgium*

Corresponding author: Ryan S. Sacko

The Citadel, Department of Health and Human Performance, 171 Moultrie St. Charleston, South Carolina, SC 29409, USA

E-mail: rsacko@citadel.edu

Abstract

Objective: To examine children's energy expenditure (EE) during object projection skill performance at three intensity intervals. Methods: Children's (42, Mage = 8.1) average metabolic equivalents of task (METs) were calculated using a COSMED K4b2 while they repeatedly performed blocks of kicking, throwing (overhand), and striking (two-handed) during 6, 12, and 30 second interval conditions. A repeated-measures analysis of covariance examined differences in METs while controlling for skill level. Results: Data indicated a main effect for interval condition (df= 2, 123, $F = 94.36$, $p <.001$, $\eta 2 = .605$). Post hoc t-tests demonstrated decreasing performance interval times yielded progressively higher METs ($p <.001$) across the three conditions (30sec = 4.5±0.8 METS, 12sec = 6.3±1.3, 6sec = 8.3±1.6). There also was a main effect for sex (df = 1,120, $F = 52.28$, $p <.001$ $\eta 2 = .305$). Boys demonstrated higher METs at each performance interval ($p <.001$). Conclusion: Skill practice with a maximum of one trial every 30 seconds resulted in the equivalent of at least moderate physical activity (>4.0 METs) and intervals of six seconds demonstrated vigorous physical activity (>7.0 METs). Practicing/performing object projection skills, even at intervals that allow for adequate instruction and feedback (i.e., 1 trial/30sec), promotes MVPA in children.

Introduction

Participation in health-enhancing physical activities reduces chronic diseases related to sedentary behavior and obesity (Larouche, Boyer, Tremblay, & Longmuir, 2013; Laukkanen, Pesola, Havu, Sääkslahti, & Finni, 2014; Lloyd, Saunders, Bremer, & Tremblay, 2014). Physical activity guidelines recommend that children participate in a minimum of 60 minutes of moderate-to-vigorous physical activity (MVPA) every day to achieve substantial health benefits (Ogden, Carroll, Fryar, & Flegal, 2015; Ogden, Carroll, Kit, & Flegal, 2012). Unfortunately, approximately 25-80% of youth worldwide do not accumulate the recommended amounts of physical activity (Guthold, Stevens, Riley, & Bull, 2018; Dentro et al., 2014; Liukkonen et al., 2014; Colley et al., 2012; Ogden et al., 2012; Prevention & Promotion, 2011) and there seems to be limited progress in overcoming this issue (Birch, Parker, & Burns., 2011; Koh & Cook, 2013; Glickman, Parker, & Sim, 2012; Robinson, Webster, & Whitt-Glover, 2014) .

Childhood is a critical time to develop motor skills that influence physical activity habits as they are the building blocks for more complex movements that are inherently linked to participation in various leisure time games, sports and activities (Clark & Metcalfe, 2002; Stodden et al., 2008). Performing activities that involve continuous locomotor skills such as walking or running and participating in activities like soccer or tennis have been recommended to achieve Physical Activity Guidelines (Ainsworth et al., 2011) as the energy expenditure (EE) during these activities generally is high (Jette, Sidney, & Blümchen, 1990; Pinnington, Wong, Tay, Green, & Dawson, 2001). However, understanding how the performance of object projection motor skills (e.g., kicking, throwing, and striking) contributes to EE in children during specific practice, games, sports or when integrated in non-structured play is not known. The EE during performance of these skills is important to examine as many times these skills are specifically practiced/performed in isolation (e.g., playing catch, physical education, sport practice) and also within the context of many leisure activities (e.g., ball games) in which children routinely participate. Thus, repetitive performance of object projection skills provides opportunities not only to improve skills, but also may assist in fulfilling daily MVPA requirements (Sacko, McIver, Brian, & Stodden, 2018).

Object projection skill performance involves complex multi-joint movements that demand high neuromuscular involvement (Croix et al., 2013 Laukkanen et al., 2014; Escamilla & Andrews, 2009) as they activate large muscle groups and are generally produced with high effort. Neuromuscular demands associated with object projection skills are substantially higher than repetitive cardiorespiratory activities of moderate intensity (e.g., jogging) suggesting that EE would also be high when these type of skills are repeated in a play, practice, or skill training context (Campbell, Stodden, & Nixon, 2010; Duffield, Dawson, Pinnington, & Wong, 2004; Escamilla & Andrews, 2009). Developing object projection skill competence requires repetitive practice, which generally involves low work-to-rest intervals, as they are discrete skills that have a defined beginning and ending. In physical education and sport practice, low work-to-rest intervals also may be a function of instruction and feedback by teachers and coaches as well as specific game-play contexts. Promoting high effort levels also is a prerequisite to developing advanced levels of object projection skills as the emergence of more advanced coordination patterns inherently includes the exploitation of neuromuscular mechanisms that necessitate high effort eccentric/concentric muscular contractions (Cattuzzo et al., 2016; Croix & Korff, 2013; Girard, Micallef, & Millet, 2005; Langendorfer, Roberton, & Stodden, 2011) that also produce high ground reaction forces and power (MacWilliams, Choi, Perezous, Chao, & McFarland, 1998; Orloff et al., 2008).

The Youth Compendium for Physical Activity was developed to provide normative EE values for many common physical activities (Butte et al., 2017) with specific consideration to children’s maturational differences (e.g., muscle mass to total mass ratio, pubertal changes)

(Malina, Bouchard, & Bar-Or, 2004; Rowland, 2005). The Youth Compendium uses pediatric data exclusively to address limitations of the original Compendium for Physical Activity (Ainsworth et al., 2011), which was informed by adult data. An important difference in the compendia is that children's metabolic equivalent of task (MET) values are noted to be higher (4.0 METs = moderate, ≥ 7.0 METs = vigorous) than adults (3.0 METs = moderate, ≥ 6.0 METs = vigorous; Butte et al., 2017).

Current research referenced within the Youth Compendium; however, offers little insight into the EE associated with object projection skills (Butte et al., 2017). The only specific example of EE during object projection skill performance suggests that "playing catch" is categorized as a "light" intensity activity (3.5 METs) in 6-9 year-old children. EE levels during the repetitive practice of object projection skills in adults has recently been shown to be equivalent to adult MVPA (≥ 3 METs) when performed at intervals of as few as two trials per minute (Sacko et al., 2018) and equivalent to vigorous activity (≥6 METs) with 10 trials per minute, but EE data on children's object projection skill performance is not available. Furthermore, the Youth Compendium does not offer insight into the variability of EE in performance (i.e., differences in METs based on cadence, effort or skill levels) at which these skills could be performed (Butte et al., 2017).

While children demonstrate a wide range of skill levels across childhood, no research has addressed the impact that differing levels of skill has on EE in children. Higher performance levels of discrete skills are associated with improved coordination and more effective transfer of energy through the body (Lloyd et al., 2014; Stodden, Langendorfer, & Roberton, 2009); thus, there may be an assumption that higher skilled individuals may demonstrate lower EE as a result of more efficient movements (Sparrow & Newell 1998). However, higher accelerations and limb speeds demonstrated by more skilled individuals during object projection skill performances require greater forces not only to accelerate (with high effort), but also decelerate (i.e., high eccentric loading, increased ground reaction forces) limbs and the performers center of mass during the completion of each individual object projection skill (Girard et al., 2005; Langendorfer et al., 2011; MacWilliams et al., 1998; Orloff et al., 2008; Pandy & Zajac, 1991; Pfeifer, 2015; Roberton & Konczak, 2001). These high effort accelerations and decelerations are associated with high neuromuscular demand. Thus, it may be plausible that more highly skilled individuals demonstrate higher EE during object projection skill performance as they may require greater EE, not only to effectively produce the performance outcome (i.e., higher performance) with high effort, but also to effectively decelerate multiple limbs and their center of mass at the end of each object projection skill performance.

Understanding EE during object projection skill performance has the potential to inform physical activity interventions by demonstrating the EE associated with performing these types of skills in isolation (i.e., practice) or during developmentally appropriate activities. Activities that require at least 4.0 METs are classified as moderate intensity physical activity in children, with > 7.0 METs being classified as vigorous intensity physical activity (Butte et al., 2017). Thus, understanding the EE during object projection skill performance will provide knowledge on the acute benefits that performing and developing these types of skills has on children's health via their contribution to daily physical activity levels as well as the long-term implications (i.e., potential benefits of developing higher skill levels) for promoting physical activity habits and behaviors (Cattuzzo et al., 2016; Logan et al., 2014; Robinson et al., 2015). The purpose of this study was to examine boys and girls EE during object projection skill performance across three different intensity interval conditions and the potential influence of skill level and sex on EE.

Methods

A convenience sample of 42 elementary school-aged children aged 7-9 years (22 boys; *M* = 8.1 yrs, *SD* = 0.8) were recruited for this study. The study was approved by the University of

South Carolina's Institutional Review Board and ethical treatment of participants was followed. Parents of participating children provided consent and all children provided assent. Children with physical disabilities or medical conditions which prevented them from completing testing were excluded from this sample. Disqualifying conditions included those: (a) who were under the care of a physician that excluded them from physical activity (e.g., heart condition, chest pain, injury, chronic illness, limb deformity) (b) who were taking prescription or non-prescription medications or used an inhaler (c) who had high blood pressure or cholesterol (d) who had suffered a seizure, asthma, lung disease, vertigo, and diabetes. The parent of each participant self-identified the race/ethnicity of their child as 88% Caucasian, 8% African-American, 2% Hispanic, and 2% Asian/Pacific Islander.

Procedures

Children participated in three nine-minute sessions where participants performed rounds of five kicks, five throws, and five strikes in a blocked fashion, at three different trial intervals (i.e., 6, 12, and 30 second intervals). Each participant completed the three experimental sessions in a randomized order. Participants were instructed to perform all trials with maximum effort. The interval schedules ranged from more intense (i.e., 6 second intervals to less intense intervals (i.e., 30 second intervals) reflecting intensity levels observed in different practice, instruction, or physical education environments (Sacko et al., 2018). Each interval session was followed by a cool down period in a seated position that lasted a minimum of 10 minutes to allow a return to resting state metabolism (Melby, Scholl, Edwards, & Bullough, 1993).

Maximal kicking and throwing ball speeds (Table 1) were recorded during the 30 second trial using a radar device (STALKER Inc. Plano, TX) to assess skill levels (Roberton & Konczak, 2001; Stodden, Langendorfer, Fleisig & Andrews, 2006a; Stodden, Langendorfer, Fleisig & Andrews, 2006b) and its potential influence on METs (Sacko, Brazendale, et al., 2018). Maximal effort throwing and kicking (five trials each) speeds for the total sample were *z*-transformed, summed and used to control for skill level. Speeds also were recorded intermittently during the 6- and 12-second trial intervals to understand whether high effort levels were maintained. Children were prompted to provide maximum effort (e.g., "throw as hard as you can") during the beginning of each round of trials for each skill and children were periodically reminded to perform maximally throughout each set of trials. A foam ball (diameter = 21.6cm, weight = 185g; Rainbow® DuraCoat Squeeze™, Gopher, MN), a regulation size tennis ball (diameter = 6.7cm, weight = 56g; QuickStart® 78, Gopher MN) and a softball size plastic ball (diameter = 10.2cm, weight = 42g; ResisDent Ball, Gopher, MN) with an 'oversized' plastic bat (diameter = 11.4cm, length = 71.1cm, weight = 90.7g; Phenom™ bat, Gopher, MN) were used for kicking, throwing and striking respectively. These implements were chosen with consideration for their similarity to a wide range of implements which may be used in physical education settings and for the safety of participants.

Anthropometric measures (i.e., mass, height) were collected prior to testing in accordance to standardized measurement procedures (Trost, 2001). (Table 1) Anthropometric measurements were assessed by trained staff with the participants wearing light (≤ 90 g) weight workout clothing without shoes. Height was measured using a portable stadiometer to the nearest 0.1 cm (ShorrBoard® Portable Height-Length Measuring Boards, Olney, MD). Mass was measured using an electronic scale (TANITA, SC-331S, Itabashi-ku, Tokyo).

****Insert Table 1 near here****

On the first of two days of testing, each participant was familiarized with all testing equipment and procedures. Children were allowed to complete as many practice trials of object projection skill performance as they desired to be familiarized with the testing process. During the second day of testing, which was separated from day one by no less than 48 hours to allow recovery from the day one practice session, each participant completed three experimental object projection skill performance sessions (i.e., 3 motor skill interval sessions) in a randomized order. Participants performed a general warm-up prior to testing which included dynamic flexibility exercises related to the specific assessments and a self-determined number of repetitions performing each specific skill. Participants were prompted to begin their performance for each trial using a prerecorded set of instructions created by two of the authors (initials removed for blinding purposes). Immediately following the instructions the recording gave a 3-second count down prior to the sound of a beep that was set according to the interval trials of 6, 12, or 30 seconds. Participants were allowed to approach each performance trial movement in a manner of their choosing (e.g., no-step approach or stepping approach). No visual instructions were given prior to testing to ensure that participants' performance would not be influenced by instructional modeling.

Indirect Calorimetry

The estimation EE during object projection skill performance trials was measured using a COSMED K4b2 portable gas exchange system, which is used to collect expired respiratory gases on a breath-by-breath basis to measure oxygen consumption (VO_2 $kg^{-1}\cdot min^{-1}$) and calculate METs (Duffield et al., 2004). The K4b2 unit was calibrated with standard gases prior to each measurement session and worn according to product specifications. METs were averaged using data collected during minutes 4-8 of each nine-minute object projection skill performance session (Sacko, Brazendale, et al., 2018). Resting state VO_2 measurements were collected prior to the start of interval sessions to establish baseline values of METs. Baseline MET values were used to ensure a sufficient amount of rest (i.e., minimum of 10 minutes) had been provided between trial sessions.

Data Analysis

Participant descriptive statistics and skill levels were calculated and reported as means (+/-SD) for the total sample and by sex (see Table 1). A repeated-measures analysis of covariance (ANCOVA) was conducted to examine differences in METs between boys and girls across the three conditions. To examine the potential impact of skill level on METs, a composite score based on the *z*-scores of throwing and kicking ball speeds was included as a covariate in the analysis (Stodden et al., 2009; Stodden, Gao, Goodway, & Langendorfer, 2014). Striking skill was not included in the composite score because of the lack of the reliability in measuring striking skill with the radar device. Bonferroni post-hoc pair-wise comparisons were used to further examine significant main and interaction effects. The alpha level was set at $p \leq .05$ and partial η^2 was reported as a measure of effect size. All analyses were conducted in SPSS 23 for Windows (IBM Corp., Armonk, NY, USA).

Results

The average EE for the three different interval conditions (6s, 12s, and 30s) are reported in Table 2.

****Insert Table 2 near here****

Results of the repeated measures ANCOVA indicated a significant main effect in EE for interval condition ($F = 331.36$, $p < .001$, partial $\eta 2 = 0.946$). Post-hoc analysis revealed that children displayed progressively higher levels of metabolic expenditure in conditions with increased trials per minute ($p < .001$; see Table 2). Additionally, there was a significant main effect for sex ($F = 17.37$, $p < .001$, partial $\eta 2 = 0.308$) with boys demonstrating higher METs than girls (see Table 2). Post hoc analyses demonstrated higher MET levels across increasing trials per minute in both boys and girls (p values < .001).

****Insert Figure 1 near here****

The results also revealed a significant interaction between sex and condition ($F = 9.09$, $p < .001$, partial $\eta^2 = 0.189$). Follow-up analyses revealed that boys demonstrated significantly higher MET levels than girls in each condition (p = .014, .002, <.001 at 30s, 12s and 6s interval respectively). The sex X condition (e.g., 30s, 12s, or 6s) interaction demonstrated greater differences in MET levels between boys and girls across interval conditions (see Figure 1 or Table 2). Finally, skill level was shown to be a significant covariate in the analyses (F = 9.67, p = .003, partial η^2 = 0.199) with higher skill being associated with greater metabolic expenditure.

Discussion

The purpose of this study was to examine children's EE during object projection skill performance at three different intensity interval conditions and the potential influence of skill level and sex on EE. Results of repetitive object projection skill performances at 6, 12, and 30-second trial intervals demonstrated that average MET values in both sexes during all interval conditions were greater than the value associated with the threshold for children's MVPA (4.0 METs). Overall, 21 of 22 boys and 16 of 20 girls demonstrated the 4.0 MET level associated with MVPA during the 30 second trial interval. Thus, similar to recently published adult data (Sacko et. al., 2018), object projection skill performance at an interval of only two trials per minute (i.e., 30-second interval) resulted in MVPA for 88% of children in this sample. These data illustrate that the accumlation of multiple high effort skilled movement performances at designated intervals are an effective method of producing levels of EE equivelent to MVPA. In addition, the average MET levels of both boys (9.3) and girls (7.2) during the 6-second interval condition demonstrated EE associated with vigorous activity (> 7.0 METs) and for boys (7.0) in the 12-second interval condition. Thus, providing opportunities to practice and perform object projection skills can provide an important contribution to both boys' and girls' daily MVPA levels, regardless of skill level. In addition, providing the necessary practice and performance opportunities to develop these skills is critical as the performance of objection projection skills is important to promote positive long-term developmental trajectories of physical activity, fitness, and a healthy weight status that spans into adulthood (Robinson et al., 2015; De Meester et al., 2018; Cattuzzo et al., 2016; Rodriguez et al., 2016; Lima et al., 2017; Stodden et al., 2009, 2013)

Contribution of Skill level to Energy Expenditure

Boys demonstrated significantly higher object projection skill levels (i.e., ball speeds) and METs than girls ($p < .001$), indicating that the development of skilled performance is beneficial for acute EE. Thus, increased joint ranges of motion and velocities (i.e., trunk, shoulder and elbow) and more developmentally advanced approach (i.e., greater linear translation of the center of mass) demand greater neuromuscular involvement (i.e., higher concentric and eccentric muscle activation and higher ground reaction forces) associated with higher skill levels (Langendorfer, Roberton & Stodden, 2011; McWilliams et al., 1998; Escamilla et al., 2009; Fleisig et al., 2009; Southard 2009; Stodden et al., 2006a; Stodden et al., 2006b Urbin et al., 2013; Lees et al., 2010).

Results indicate that sex differences (i.e., boys demonstrated greater EE than girls across all conditions) in this age band (7-9 years), were independent of skill level (i.e. skill performance) as the ANCOVA indicated skill level independently covaried with EE across interval conditions and sex. The age group chosen limited the potential influence of maturational differences on EE (Freitas et al., 2015; Luz et al., 2016). The role that actual effort level may play in the production of EE during discrete tasks is not yet fully understood and may play a role in metabolic expenditure during performance. Thus, while participants performed skills with high effort levels, the rest intervals between individual object projection skill trials (i.e., 6s, 12s, or 30s) may have been more influential on accumulated levels of objectively measured EE than sex, skill, or level of effort.

Overall, these data represent the first step in establishing MET values for the repetitive practice of object projection motor skills in children. Furthering our understanding of potential mediating factors that influence EE and skill level is an important future direction of research as results may provide insight for the practice and acquisition of object projection skills as a supplemental choice for engaging in health-enhancing physical activity, specifically in young children who may concurrently benefit from skill development to accumulate recommended levels of MVPA.

Implications for instruction and practice

Childhood is a critical time for the development of object projection skills as they are the building blocks for more complex skills and developmentally appropriate activities (Clark & Metcalfe, 2002) that do not develop "naturally" (Stodden et al., 2008) Thus, it is critical that sufficient opportunities for motor skills to be taught, practiced, and reinforced are provided. This study indicates that the achievement of MVPA during the practice of object projection skills can be achieved when performed at a rate of a minimum of two high effort trials per minute. Thus, the time between trials performed at a rate of one performance every 30 seconds allows for instruction and feedback of a child's performance from practitioners. As instruction and feedback are critical to promote optimal learning (Magill, 2014, these data suggest that practicing object projection skills at only two trials per minute provides both health enhancing physical activity and allows time for critical instruction and feedback to optimize learning. This information should be specifically utilized when developing physical activity interventions as data from this study has both acute and long-term ramifications for promoting the health, well-being, and overall development of children. In addition, practicing at a rate of at least 5-10 trials per minute (i.e., free play or structured practice/game play) may provide a metabolic response equivalent to vigorous activity, thus providing even greater health benefits in the short term (Haskell, et.al., 2007).

Research suggests the percentage of time in MVPA in physical education classes or recess (as measured by accelerometers or pedometers) rarely meet the recommended guidelines of; spending 50% of class time in MVPA (Nadeau, Maahs, Daniels, & Eckel, 2011; Prevention &

Promotion, 2011) for accumulating 60 minutes or more of MVPA per day (Ogden, Carroll, Fryar, & Flegal, 2015; Ogden, Carroll, Kit, & Flegal, 2012). However, these data suggest that MVPA levels in physical education, leisure games, and sport participation that involves repetitive performance of object projection skills may be higher than previously captured by current PA assessment devices due to the intermittent nature of object projection skill performance and limited vertical excursions of an individual's center of mass (Sacko., et al., 2018; Sacko, Brazendale, et al., 2018). Thus, research that examines the contribution of practice and performance of object projection skills on the achievement of recommended daily values of MVPA in activities performed by children in games, leisure activities practice and sports, where object projection skills are routinely performed, is warranted.

Limitations

A limitation of this study includes a lack of understanding of the relative contribution of each skill (kicking, throwing, or striking) toward the production of EE. In an effort to reduce potential overuse and joint-related injury risk as a result of repeated high effort trials of independent motions, this study alternated the performances of all three skills in blocked fashion (i.e., repeating 5 kick trials, then 5 throw trials, then 5 strike trials). As a result of this study's design the ability to make inferences on the EE contribution of each independent skill performance is limited. However, the individual EE contribution relative to each skill performance should be similar as all three skills involve similar physical (i.e., multi-joint object projection skills), physiological (i.e., gross neuromuscular involvement), and mechanical (i.e., kinetic chain) mechanisms (Langendorfer et al., 2011). An additional contributing factor that may have influenced EE is a child's motivation to perform with maximal effort. To limit the potential impact of a decrease in motivation on individual performances, instructions to perform with maximal effort were continually provided to individuals throughout each session.

Individual trial speeds also were recorded intermittently during the 6- and 12-second trial intervals to promote and maintain participants' consistent high effort levels.

Conclusions

This study adds to current literature as it is the first study to measure EE levels during object projection skill performance using indirect calorimetry in children. Results indicate skill practice with a maximum of one trial every 30 seconds resulted in the equivalent of at least moderate physical activity and intervals of 12 and 6 seconds demonstrated vigorous physical activity for most individuals. This also is the first study to also demonstrate that skill level has a significant role in the production of EE during object projection skill performance in children. These data have the potential to significantly impact physical activity intervention strategies and the implementation of physical education curricula by noting that practice of object projection skills do, in fact, produce MVPA levels. These data also provide an understanding of how specific trial interval intensity levels are associated with differences in EE (i.e., moderate to vigorous). Information gleaned from this study provides evidence that the practice of object projection skills aids in the achievement of not only acute levels of health-enhancing physical activity, but also the promotion of a foundation for skill development that promotes lifelong physical activity.

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Disclosure of interest

The authors report no conflicts of interest.

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Table 1.
Physical characteristics of participants

	Boys (n = 22)	Girls (n = 20)	All Participants (N = 42)
Age, years	8.1 ± 0.8	8.0 ± 0.8	8.1 ± 0.8
Height, cm	133.8 ± 3.9*	135.0 ± 4.0	134.4 ± 7.6
Body mass, kg	33.2 ± 4.3*	30.0 ± 6.6	29.1 ± 5.6
Kick, mph	42.0 ± 6.9*	28.3 ± 8.3	27.8 ± 7.6
Throw, mph	37.9 ± 8.7*	25.7 ± 5.5	30.7 ± 8.7

*Values presented as means ± SD; n, number of subjects; *Significantly different from girls p < .01*

Table 2.
Measured gross energy expenditure (METs) during object projection skill performance

	6 second (METs)	12 second (METs)	30 second (METs)
Boys	9.3 ± 1.4*	7.0 ± 1.1*	4.8 ± 0.7*
Girls	7.2 ± 1.2	5.6 ± 1.1	4.1 ± 0.7
Total	8.3 ± 1.6	6.3 ± 1.3	4.5 ± 0.8

*Values presented as means ± SD; METs, metabolic equivalent of task; *Significantly different from girls p < .01.*

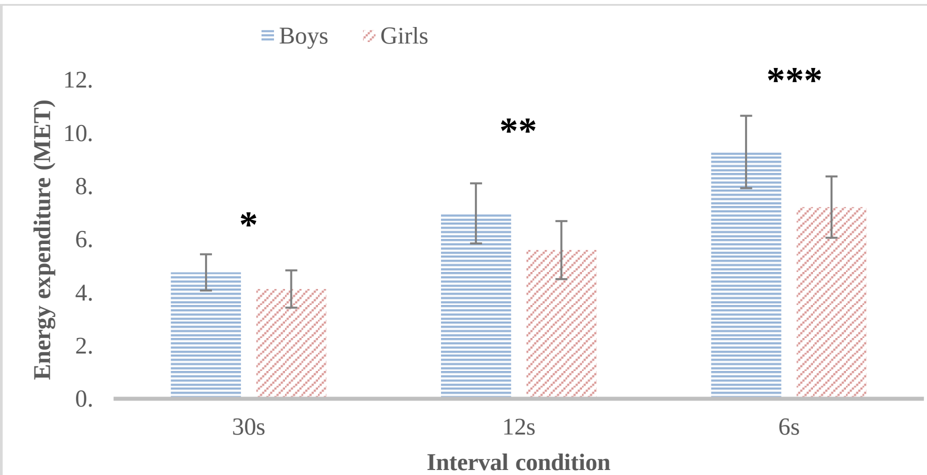

Figure 1. Comparison of mean MET (metabolic equivalent of task) values between boys and girls across the three conditions, ***p < .001; ** p < .01; * $p \leq$ .05.